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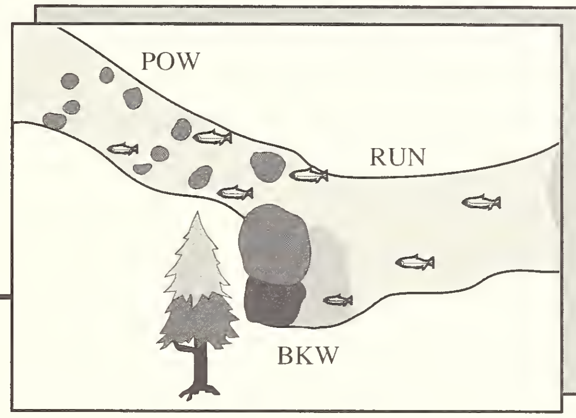

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Comparison of Habitat Use and Availability for Juvenile Fall Chinook Salmon in A Tributary of the Smith River, CA

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Abstract

Habitat use and availability for two cohorts (1987-88) of juvenile chinook salmon were monitored from emergence to emigration. Their distribution was observed among several habitat types at regular intervals in the lower seven kilometers of Hurdygurdy Creek, a tributary to the South Fork Smith River in Del Norte County, California. Stream habitat was quantified on the scale of pools, riffles, runs, and edgewaters. Seasonal shifts in observed habitat utilization were from backwater-edgewater in spring to pool habitat in summer. Habitat availability was described as total surface area and was dominated by riffles, runs, and pools. Backwater-edgewater habitat comprised at most two percent of the total stream area. Habitat availability changed seasonally, with some edgewater units drying up by mid-summer. The length of time juvenile chinook were observed in the study reach differed between years. Storms in May-June 1988 may have influenced the availability of early spring refuge habitat. During both years, total observed juvenile chinook abundance for the 32 units sampled increased rapidly during emergence in spring, peaking on May 8, 1987 and May 17, 1988, then decreased sharply through early June of both years. Comparison of habitat use and availability indicated that newly emerged juvenile chinook salmon preferred scarce backwater-edgewater habitat, while individuals remaining through the summer preferred more abundant pool habitat.

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Introduction

This paper summarizes a study of habitat preference by juvenile fall chinook salmon in a reach of Hurdygurdy Creek, in the Smith River drainage, a coastal river system in the Siskiyou Mountains of Northern California. Both temporal and spatial aspects of habitat use and availability are considered in terms of changes in habitat distribution in relation to ontogeny, population density, and hydrologic fluxes on seasonal and year-to-year time scales. Habitat preference exhibited by juvenile chinook salmon is discussed as it is defined by Johnson (1980) and Alldredge and Ratti (1986), where it is assumed that preference is implied by comparing habitat use to habitat availability. The relationships between habitat use and fish density, i.e. the degree that habitat suitability is density dependent, is discussed with reference to the Fretwell-Lucas Theory of habitat distribution. The management implications of these points are discussed, specifically in applying ecological theory to fish habitat management and the utility of anadromous fish as biological indicators of land use effects.

Background

Fall chinook salmon of the Smith River exhibit a life cycle and ontogeny typical of this anadromous species. Spawning occurs throughout the mainstems and lower reaches of major tributaries in fall and winter. Larval hatching and emergence from the gravel occurs from late winter through early spring, with embryo development rate determined by water temperature. Juveniles rear for a variable period in their natal streams then migrate toward the estuary and seaward during smoltification. The fish grow and mature in the ocean for approximately two to six years, then return to their natal streams to spawn.

For salmon, certain habitats are of utmost importance in completing specific life stages. The range of tolerance a species has for any given environmental variable changes during growth and development, with larval life stage requirements often having the narrowest limits (May, 1974). The suitability of habitats utilized may vary from tolerable to optimal. Environmental changes can affect habitat suitability over several time scales: weekly, seasonally, and yearly. Large storm events can impact habitat on a large scale (pool-riffle ratio, reach gradient) and can change habitat suitability for several years (Lisle, 1981).

Selective use of habitat by a fish is an illustration of an organism attempting to meet its habitat requirements. Habitat selection infers that fish actively seek a preferred set of conditions that exist in a larger set or wider range of tolerable limits. Habitat preference drives the act of selection and has been quantified by comparing habitat use to availability (Johnson, 1980; Alldredge and Ratti, 1986) Preference is expressed when habitat is used disproportionately to its availability. In this study, I assume the degree of habitat preference exhibited by juvenile chinook salmon to be a potential indicator of which habitats are critically necessary in its life history.

In this study, habitat was quantified on the reach scale. Naturally occurring pools, riffles, and runs were recognized as habitat units. This allows fish habitat use and distribution to be viewed with regard to fluvial processes, channel morphology, and structural elements. Pool-riffle or step-pool sequence development is a fundamental stream channel process (Yang 1971). This process in concert with localized flow obstructions and disturbances (e.g. log jams, bedrock outcrops, slides, and boulders) results in a meandering channel with complex form, hydraulics, and topography where dis-

crete channel units or habitat types can be recognized (Beschta and Platts, 1986; Hankin and Reeves, 1988).

This fundamental characteristic of stream channels and its relationship to fish ecology was recognized by Bisson et al. (1981) who applied it in developing a system of naming habitat for the purpose of describing habitat use in small streams in western Washington. Beginning in 1984, Lynn Decker, Dave Fuller, and Tom Lisle of the US Forest Service at PSW Arcata tested this system's utility in studying fish habitat relationships in Hurdygurdy Creek. After some expansion, this system was successfully applied, yielding a basin wide habitat inventory of Hurdygurdy Creek. The inventory work resulted in a new view of the stream, and questions on relationships of the abundance and distribution of habitat to fishes began emerging, one of which was: what is the level of use and availability of various types of pools, riffles, and runs pertaining to juvenile chinook salmon during their residence in Hurdygurdy Creek? My study is an attempt to address this question.

Methods

I recorded habitat use and preference by two cohorts (1987 and 1988) of juvenile chinook salmon from emergence to outmigration by monitoring habitat area and observing their distribution with regard to habitat strata at regular intervals. As a sampling framework, I used a stream habitat stratification scheme where eight habitat types were delineated followed criteria set up by Bisson et al. (1981), and McCain et al. (1990), and are as follows: Low Gradient Riffle (LGR), High Gradient Riffle (HGR), Edgewater (EDG), Run (RUN), Backwater Pool (BKW) (also termed alcove or eddy), Lateral Scour Pool (LSP), Channel Confluence Pool (CCP), and Mid Channel Pool (MCP) (Figure 1).

Randomly selected units were mapped to measure their surface area. All measurements were made to the nearest 0.1 meter. Due to fluctuating stream discharge and subsequent changes in habitat area, mean width of each unit was monitored throughout the study.

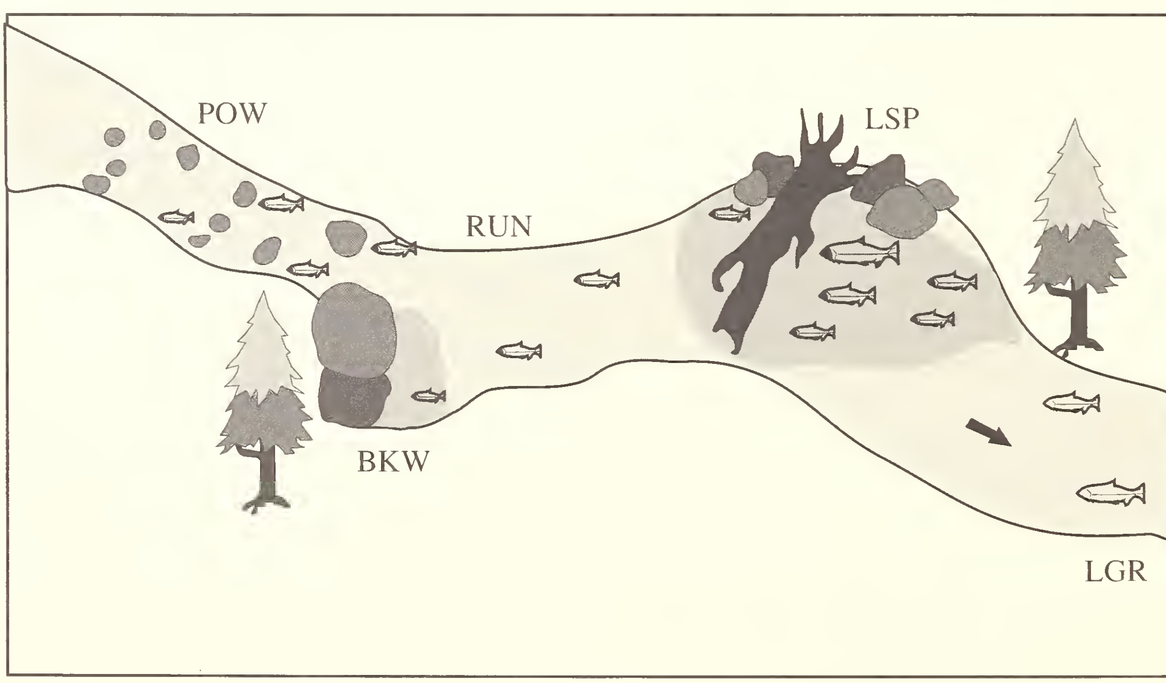

Figure 1. Fish distribution among habitat types.

Habitat units were randomly selected from an initial habitat inventory (McCain et al., 1990), where units of each type were identified and numbered sequentially, from the stream mouth proceeding upstream, and selected with the use of a random number generator.

Paired divers using underwater direct observation techniques modified from Edmundson et al. (1968), Griffith (1983), and Hankin and Reeves (1988) counted juvenile chinook salmon in each habitat unit every three to six weeks from April 16, 1987 to December 1, 1988. Divers used pencils and Plexiglas slates to tally observed numbers of juvenile chinook salmon in each unit. The divers moved slowly, making no abrupt movements while in the water to minimize the frightening of fish (Edmundson et al. 1968).

The habitat units were observed in the same order each visit, starting at the downstream-most unit and proceeding upstream. Observations took place primarily between 1000 and 1600 hours DST. Five to eight units were observed per day, with each set of 32 total observations spanning approximately six days. Cross validation of visual fish counts by comparing observed numbers to those obtained by removal methods, namely electrofishing and poisoning, was not performed. This study required monitoring specific units repeatedly over time to detect changes in fish distribution within the units. Removal methods would have the potential to affect the temporal and spatial distribution of fish not only at the sampling site, but also downstream throughout the study reach.

The fish counts and habitat area estimates for each discrete observation period were used to calculate an index of fish density in each habitat unit for each observation period. The density index is assumed to indicate the relative degree of habitat use. For each observation period, a hypothesis was tested: observed juvenile chinook salmon density, or habitat use, is similar throughout the eight habitat types. The hypothesis was tested using non-parametric Kruskal-Wallis ANOVA of ranks from Minitab statistical software. For each habitat type, the average rank and associated z-value were calculated, where:

$$z_i = \frac{\dfrac{\text{Average rank} - (N+1)}{2}}{\sqrt{\dfrac{(N+1)(N/n_i-1)}{12}}}$$

$n_i = 4$ = number of units sampled in each habitat strata

$N = 32$ = total number of habitat units sampled.

Under H_o, z_i is approximately normal with mean 0 and variance 1. For each period, the group of z-values illustrates the relative degree of average use of each habitat type by juvenile chinook salmon at that time. Habitat availability for the reach of study was derived from the initial inventory of the entire lower seven km of stream. Total area for each strata was converted to percent of total reach area. Relative differences between habitat availability percentages were then compared to the relative differences in each set of time specific mean density indexes and utilization z-values to allow interpretation of the relative degree of habitat preference. For example, a relatively high habitat use index compared to a low habitat type availability percentage indicates a potential preference by fish for that habitat type.

Results

Habitat Use

Observations of rearing juvenile chinook in Hurdygurdy Creek indicate that temporal shifts in habitat utilization occurred as a shift from backwater-edgewater habitat types to pool habitat. The length of time juvenile chinook were observed in the study reach differed between years. The 1987 cohort was observed in some of the selected units from emergence in April through November 21, while those of 1988 were observed in the units only through late August. During both years, overall observed juvenile chinook abundance for the total 32 units sampled increased rapidly during emergence in spring, peaking on May 8, 1987 and May 17, 1988, then decreased sharply through early June (Figure 1.).

The highest mean observed habitat use by juvenile chinook salmon during May, 1987 and 1988, occurred in backwater habitat where newly emerged fish were feeding in small aggregations of 20 to 40. Use was significantly higher in these habitats than in the remaining units, as illustrated by the relative high z-values in Table 1 (H=20.03 and 21.68, with P=0.01 and 0.00 respectively for 1987 and 1988). Each value of the H statistic indicates a very high deviation from a hypothetical expected habitat use profile (where all z-values = 0), and is comparable to a chi-square value at k-1 (7) degrees of freedom. Backwater habitat units selected for the study were characterized by slow shallow water and were relatively homogeneous in depth and velocity. Three of the four backwater units selected were associated with instream boulder enhancement structures. During May, newly emerged chinook were also observed in lower abundances in pool habitat feeding in groups of 10 to 50 in margin and pool tail areas, behind large bedrock obstructions, and under rootwads and overhanging banks. By late June, observed habitat use had sharply decreased in backwater habitat with the highest use shifting to pools, where fish were actively drift feeding near the surface in open deep areas devoid of cover. Z-values (Table 1) indicate summer use was highest in lateral scour, channel confluence, and mid channel pools. However, H statistics and alpha levels in Table 1 imply that the degree of and pool utilization in July and August was more significant in 1987 than in 1988. For example, P = 0 for both habitat type and zone at August 25, 1987; whereas P = 0.19 and 0.12 respectively for habitat type and zone for August 27, 1988.

Habitat Availability

Habitat availability for main channel habitats remained at a fairly constant ratio throughout the study. Habitat types associated with stream margin fluctuated most, with two edgewater units drying out by late summer of both years. Margin zones which extended as wide shallow areas also decreased in size as summer progressed. Pool habitat units with steep side slopes had a nearly constant surface area through time.

Discussion

In the Smith River, habitat primarily used by juvenile chinook salmon for early rearing is characterized by slow velocity and cover (e.g. rootwads, boulder deflectors, and overhangs). These areas may serve as a refuge from predation and high spring flows during emergence, and also may provide abundant prey items of appropriate size. Backwater habitat comprises only one percent of the total surface area of the study reach, a condition that may be limiting emergent survival and early rearing success.

1987											
% Total Area	4/16	5/8	5/29	6/21	7/14	8/3	8/25	9/15	10/8	10/30	11/21
LGR 30	-.2.05	-2.88	-2.19	-2.05	-1.65	-1.82	-1.82	-1.71	-1.60	-1.25	-0.57
HGR 20	-1.94	-2.05	-1.71	-1.48	-1.31	-1.82	-1.82	-1.71	-1.60	-1.25	-0.57
EDG 1	-0.91	0.60	-1.05	-1.31	-2.17	-1.82	-1.82	-1.71	-1.60	-1.25	-0.57
RUN 23	0.11	-1.03	-0.88	-0.57	-0.17	0.14	-0.03	0.00	-0.40	-0.28	0.40
BKW 1	$\boxed{2.56}$	$\boxed{2.45}$	0.71	-0.74	-1.31	-1.00	-0.88	-0.40	-0.60	-1.25	-0.57
LSP 9	0.06	1.25	1.20	$\boxed{2.39}$	1.99	1.48	1.42	1.20	1.57	1.88	$\boxed{1.37}$
CCP 6	0.74	0.74	1.88	1.99	$\boxed{2.45}$	2.34	2.28	$\boxed{2.17}$	1.99	1.37	0.23
MCP 11	1.42	0.91	2.05	1.77	2.17	$\boxed{2.51}$	$\boxed{2.68}$	$\boxed{2.17}$	$\boxed{2.22}$	$\boxed{2.05}$	0.28
H stat.	15.73	20.03	17.42	19.89	23.96	24.92	25.14	20.30	20.77	19.48	7.58
p	0.03	0.01	0.01	0.01	0	0	0	0	0	0.01	0.37

1988					
% Total Area	4/2	5/17	6/20	7/20	8/27
LGR 30	-0.46	-2.62	-2.62	-1.71	-0.91
HGR 20	-0.46	-2.62	-1.94	-1.71	-0.91
EDG 1	-0.46	0.91	-1.14	-1.71	-0.91
RUN 23	$\boxed{1.25}$	0.68	-0.34	0.34	-0.14
BKW 1	-0.46	$\boxed{2.96}$	$\boxed{2.85}$	0.34	0.09
LSP 9	0.48	0.63	1.31	$\boxed{1.99}$	0.03
CCP 6	0.54	0.11	0.74	1.42	$\boxed{1.74}$
MCP 11	-0.46	-0.06	1.14	1.03	1.03
H stat.	8.31	21.68	21.22	16.52	9.97
p	0.31	0	0	0.02	0.19

Table 1.
Z-values for 1987 and 1988 cohort of chinook salmon. Boxed numbers are the highest Z-values for each observation period.

In the study reach, large woody debris (LWD) is a primary element in forming potentially critical early rearing backwater habitat, with boulder habitat improvement structures often placed in the channel to serve as 'LWD substitutes'. Extensive removal of debris jams along with salvage of standing potential LWD after wildfire, windstorms, and disease outbreaks in the past century has resulted in a possible long-term deficit in the LWD budget of many forest watersheds throughout the West (R. Ruediger and J. Sedell, pers. comm.). If abundance and distribution of backwater habitat in forest streams is largely determined by the amount and distribution of LWD in the channel, then addressing the problems of sources and recruitment of LWD are therefore key in managing watersheds for productive stream habitat.
Pool habitat used by juvenile chinook salmon in later stages of rearing is much more abundant than edge- and backwater types (approximately 25 percent of the study reach surface area). This may imply that availability of pools is not likely to be limiting the juvenile chinook population in Hurdygurdy Creek.

Comparison of the relative differences in degree of habitat use, indicated by each time specific set of z-values, to the differences in habitat availability indicate potential habitat preferences. A relatively high degree of preference for backwater habitat was exhibited in spring--high use of a limited habitat.

The difference in duration of stream residency between 1987 and 1988 could be reflective of the difference in streamflow and water year. Flows in May and June, 1988, as opposed to 1987, may have been high enough to severely limit the amount of early rearing habitat in many of the available pools and literally may have flushed out much of the 1988 cohort. A greater fraction were observed in BKW during May, 1988 than the previous spring. Backwater pools may have been the only habitat suitable for the rearing juvenile chinook salmon during the high flows of May, 1988. Mason (1976) and Peterson (1982) demonstrated the influence of storm flows on habitat availability which may limit the total population.

Fretwell and Lucas (1970) discussed relationships between habitat suitability and population density for birds. Their theory argues that distribution and habitat suitability not only reflects the environmental requirements of a species, but is also density dependent. The theory predicts that the distribution of an organism at low population levels will be linked to relative optimum habitats and, as the population increases in these most suitable habitats, their relative suitability decreases, with formerly less suitable habitats becoming equally suitable. As this process continues, all available habitats ultimately become equally suitable with the organism being dispersed evenly throughout them.

If the Fretwell-Lucas theory is accurate, and habitat suitability is partially density dependent, then year-to-year population variability could mask the relationships between an organism and physical habitat parameters. The theory applied to fish populations implies that habitat suitability not only changes seasonally through ontogenetically related shifts in food and habitat requirements but also annually from inherent population variability. Going a step further to the community level, habitat suitability for each species of a fish community could change as a result of ontogenetic shifts, intraspecific competition, population density, and through interspecific interactions with other populations undergoing the same fluxes and processes. Expanding on the Fretwell-Lucas theory to encompass fish community dynamics could lead to valid but complex assumptions to use in stream ecology research, as well as in fisheries management.

Conclusions

Studies have shown that year class strength in fishes can be determined early in life (May, 1974; Reimers, 1971), with a short period of very high mortality existing in the larval/parr stage. Given the low overall survival rate of salmonids from egg to adult, an improvement in early rearing conditions could potentially improve year class strength. However, the relative importance of early rearing habitat to year class strength can fluctuate from year to year, with natal streams being only one of many environments that Smith River fall chinook salmon utilize. Overriding limiting factors associated with riverine, estuarine, and/or ocean phases of its life cycle can mask any one-to-one relationship between early rearing habitat quality and adult spawning escapement. Therefore, creating more elements which characterize early rearing habitat may benefit newly emerged chinook during their first month of stream rearing, with the effects of habitat improvements on the population as a whole highly variable from year to year.

From my work in Hurdygurdy Creek, I can roughly predict that about five percent of the 1987 and 1988 chinook salmon age 0 cohorts remained in this natal stream to rear at least through summer (Figure 2). Study of the freshwater vs. ocean growth history of several cohorts of returning spawners is necessary to qualify any stable pattern as to how the extended natal stream rearing fraction contributes to the population.

In applying the results of this kind of work toward any management guidelines, such as maintaining chinook salmon populations through the maintenance and improvement of rearing habitat, we must also strongly consider the biological parameters, as well as large-scale environmental pertubations (floods and drought), which can control fish population abundance and shape demographics. The amount of variation observed in this study of overall fish abundance between 1987 and 1988 suggests that benefits of habitat manipulations, such as creating backwaters, are highly variable from year to year.

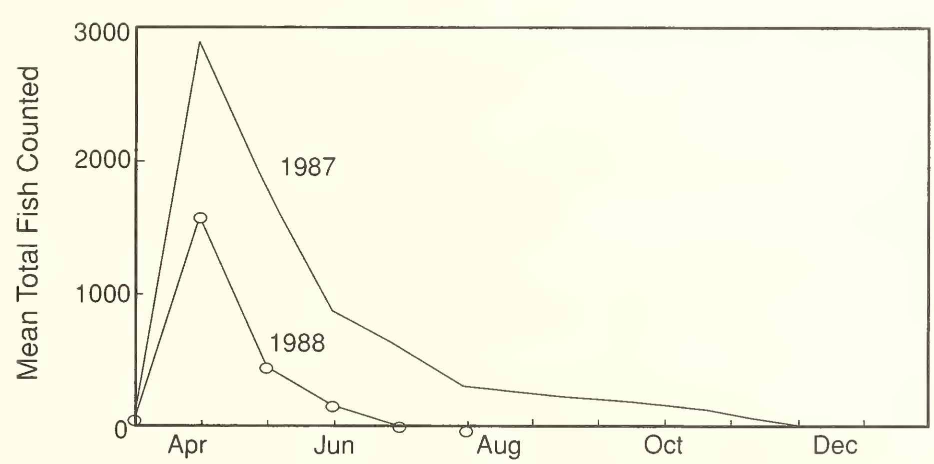

Figure 2. Mean total fish counted for each observation period for 1987 and 1988.

The links between LWD and early rearing habitat must be considered when designing habitat management programs and setting goals in terms of desired future conditions. Based on what is known of historical LWD levels in forest streams, along with knowledge on the few remaining pristine stream systems, a long term habitat management program should target LWD as a primary structural component and facilitate and enhance its recruitment and accumulation to a functional level.

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